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PATENT APPLICATION

FOR

REDUNDANT OPTICAL DEVICE ARRAY

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625293 v1

TITLE

REDUNDANT OPTICAL DEVICE ARRAY

FIELD OF THE INVENTION

This invention relates to arrays of optical devices such as lasers and photodetectors and, more particularly, to arrays of optical devices having increased yield and longer lifetime.

BACKGROUND OF THE INVENTION

Over the past few years the dramatic increase in the use of fiber optics in communications systems has created a tremendous need for both cheaper and more reliable optical components. Unfortunately, the limited materials usable to create acceptable laser diodes and photo detectors for use in such devices effectively limits the mean time between failures (MTBF) that can be achieved for such devices.

Typically diode lasers or photodetectors are fabricated by growing the devices on a semiconductor substrate. Depending upon the particular devices and there design, this may entail the use of known techniques such as liquid-phase epitaxy, metal-organic vapor-phase epitaxy, molecular beam epitaxy. Each of these techniques has its advantages and disadvantages in terms of the quality, reliability, and frequency of defect occurrence.

Once the active portion of the device is produce by the epitaxial growth process, the devices are then further processed into device chips. During these processes dielectric films and various metals are deposited on the semiconductor , for example, to isolate parts or create

contacts. Finally, photolithography and/or chemical or physical etching are used to finish the devices. Once the device structures are fully formed in the semiconductor wafer, each device is separated from the wafer, for example, by cleaving.

FIGS. 1A and 1B show two variants of an example optical device of the prior art, a semiconductor laser diode. The specific devices 110, 120 shown in FIGS. 1A and 1B are vertical cavity surface emitting lasers (VCSEL). As shown, each device 110, 120 is contained in an approximately 200 micrometer (micron) square area of semi-conductor material. Each device 110, 120 has an optical window 112, 122 of approximately 17-19 micron diameter. The device 110 ,120 is connected via a trace 114, 124 to a bonding pad 116, 126 approximately 100 microns square. In Fig. 1A, the bonding pad serves as the positive ("+") contact and in FIG. 1B, the bonding pad serves as the negative ("-") contact.

FIG. 2 shows multiple individual VCSELs that have been combined to form at least a 2 X 3 array of lasers. The devices 200 are arranged so that the spacing between each laser (i.e. the "pitch") is approximately 250 microns. Such arrays can be relatively reliable, because each individual laser device 200 can be operationally tested before it is integrated into the array. However, once the array is created, if an individual element fails, either the entire array must be replaced or the array becomes degraded because there is no easy way to repair it.

Moreover, even if the array is created from macrostructures, for example, so that there are 1 X 4 discrete devices on a common carrier. If any one of the devices is defective, the entire carrier becomes useless or the individual good devices must be removed from it and used individually.

All of the above results in arrays that are both costly to produce and, in their overall configuration, have an overall MTBF of the least reliable device in the array.

Thus there remains a need in the art for a way to produce a chip incorporating an array of optical devices that is less costly to produce.

There remains a further need in the art for an array that is easy to repair at low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B show two variants of an example semiconductor laser diode optical device of the prior art;

FIG. 2 shows multiple VCSEL's of FIG. 1 arranged in an array according to the prior art;

FIG. 3 shows a redundant laser pair from an array in accordance with the invention;

FIG. 4A shows a group of four redundant lasers from an array according to the invention;

FIG. 4B functionally shows contacts for the group of FIG. 4A;

FIG. 5 shows the functional components of an opto-electronic chip suitable for use in accordance with the invention;

FIG. 6 shows the chip of FIG. 5 employing pairs of redundant lasers according to the invention;

FIG. 7 shows an alternative variant to the chip of FIG. 6;

FIG. 8 shows the chip of FIG. 5 employing groups of four redundant lasers according to the invention;

FIG. 9 shows the chip of FIG. 5 employing pairs of redundant photodetectors according to the invention;

FIG. 10 shows a device of FIG. 5 employing groups of four redundant photo detectors according to the invention;

FIG. 11A shows one functional example of circuitry for selecting from among two or more redundant devices according to the invention;

FIG. 11B shows another functional example of circuitry from among two or more redundant devices according to the invention;

FIG. 12 functionally shows an opto-electronic transceiver incorporating the invention; and

FIG. 13 is a functional block diagram of example automatic failover circuitry for a group of two devices.

SUMMARY OF THE INVENTION

We have devised a way to create electro-optical chips that avoid the problems of the prior art.

In particular, we have created a way to deploy large numbers of optical devices in a manner which provides a higher overall yield and greater reliability. Depending upon the particular implementation, further advantages such as reparability after deployment, and performance optimization can be achieved.

One aspect of he invention involves an optical module has multiple optical devices. At least two of the multiple optical devices are a group. Each of the optical devices in the group are individually selectable relative to the others. The optical module also has a controller, coupled to

the devices such that the controller can select which of the devices in the group will be active at a given time.

Another aspect of the invention involves a method of creating an optical chip, having redundant devices, for use in an opto-electronic unit involves growing active portions of multiple optical devices on a wafer, processing the wafer to create complete optical devices, creating individual optical devices, grouping the devices; and connecting the devices in agroup to a control circuit such that, common data can be received by any of the devices in the group but the common data will only be handled by the device in the group that is active.

Yet another aspect of the invention involves a communications network that has a first transmitter having a number of usable channels, a first receiver, and optical fibers connecting the first transmitter to the first receiver. The first transmitter has multiple lasers, at least some being selectable as either active or backup lasers. The multiple lasers are controllable such that, if a specific channel is in use by an active laser and a laser failure occurs for that channel, a redundant laser can be substituted for the active laser and, after the substitution, the specific channel can be used using the redundant laser.

These and other aspects described herein, or resulting from the using teachings contained herein, provide advantages and benefits over the prior art.

The advantages and features described herein are a few of the many advantages and features available from representative embodiments and are presented only to assist in understanding the invention. It should be understood that they are not to be considered limitations on the invention as defined by the claims, or limitations on equivalents to the claims.

For instance, some of these advantages are mutually contradictory, in that they cannot be simultaneously present in a single embodiment. Similarly, some advantages are applicable to one aspect of the invention, and inapplicable to others. Thus, this summary of features and advantages should not be considered dispositive in determining equivalence. Additional features and advantages of the invention will become apparent in the following description, from the drawings, and from the claims.

DETAILED DESCRIPTION

FIG. 3 shows a portion 300 of a two dimensional array of lasers 302 created according to the principles of the invention. The portion shows two individual laser devices 302 bonded via contact pads 304 to an electronic chip 306. As shown, the devices 302 are bottom emitting laser devices that have been flip chipped bonded to the electronic chip, although as will be apparent from the description herein, bottom receiving, top emitting or top receiving devices can be used as well, particularly if the approaches of the commonly assigned U.S. patent applications entitled Opto-Electronic Device Integration filed concurrently herewith (which are incorporated herein by reference) is employed as part of the process.

Because the substrates 308 have not been removed or excessively thinned, emissions of the lasers occur via access ways 310 created in the substrate 308 on which the laser devices were supported to allow for close optical access to the devices. The spacing between the access ways, i.e. the pitch, is such that each of the lasers 302 can be either directly coupled to a single optical fiber, or directed into a common optical fiber, for example, by focusing the light output using a

micro lens or guiding the light using an optical waveguide. Thus, depending upon the particular lasers and fibers used, the pitch between the two lasers can be as small as 5-10 microns for direct lasing into a single mode fiber or 50-100 microns for direct lasing into a multimode fiber. Alternatively, if an optical wave guide or focussing lens is used, the inter-device pitch becomes less important and may be as much as a 100 microns or more as needed.

During device creation the lasers are separated into individual devices by patterning the laser wafer prior to bonding with the electronic chip, for example as shown in the incorporated commonly assigned application entitled, Opto-Electronic Device Integration. Additionally, the devices are patterned with grouping trenches 312 which physically and electrically define groups by creating boundaries separating individual groups 314 of redundant devices. The grouping trenches 312 ensure isolation among the individual groups while allowing for carrier movement among the devices within the group via the electrically conductive substrate 308.

All the devices in a group 314 share a common connection (either the positive or negative contact) so that any signal to be sent or received by any of the devices can be sent or received by any other of the devices in the group irrespective of which one is selected as being active using the contacts. In other words, if three lasers constitute a group in an optical module, such as an optical transmitter, they will be coupled to a single optical fiber, all have one contact in common and all have individual opposite polarity contacts. If the transmitter were to send data through the optical fiber, the same signal would be sent irrespective of which laser was active at the time. Moreover, from the perspective of the functions of any prior art optical transmitter, the transmitter incorporating the invention can be oblivious to which laser in the group is active.

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Advantageously, the purchaser or user of the transmitter, or any other device employing the invention, need not know it contains device redundancy. The features and elements that allow selection of the particular active laser can be wholly transparent to anyone other than the manufacturer or can be made accessible to third parties to varying degrees.

FIG. 4A shows a portion of a laser array employing groups 400 of four lasers 402 as a redundant group. As shown, the individual devices have been separated through patterning of separation trenches 404 which isolate the individual device contacts 406, and groups 400 have been created by patterning of grouping trenches 408 which isolate the common contact 410 from the common contact(s) of other neighboring groups. As with FIG. 3, access ways 310 are provided through the substrate to provide for close optical access to the lasers. FIG. 4B is a functional representation of the group of FIG. 4A but showing the discrete contacts 406 for each laser and the substrate 308, which is used as the common contact.

Advantageously, by grouping the lasers in fours, significant flexibility can be obtained. For example, the best two of the four lasers can be used as a redundant pair with or without the remaining two lasers serving as back up devices for either laser in the pair, the best of the four lasers can be employed as a primary laser with each of the remaining three being available should the primary laser fail, or should any individual laser in the group be bad, it can be disregarded entirely.

FIG. 5 shows the functional components of an opto-electronic device 500 suitable for employing the principles of the invention. Functionally, the device includes a laser portion 502 which contains an array of individual lasers. The device also includes a detector portion 504

which includes an array of individual photodetectors. A control portion 506 is provided which contains the control electronics for accessing the individual lasers and/or detectors. Additionally, a storage portion 508 can optionally be provided, as will be described in greater detail below. Finally, the device includes an interface portion 510 through which the opto-electronic chip may be electrically or programmatically connected to other devices or control electronics. Depending upon the particular implementation, the interface portion 510 may be functionally located between the control portion 506 (and/or the storage 508 if this option is used) and the devices 502, 504, for example where the control 506 and/or the storage 508 can be provided by a third party. In other variants, the interface 510 may provide a way to bypass or override either or both of the control portion 506 and/or storage 508 if either or both are present.

Functionally, the control portion 506 is, in whole or part, the "brains" of the opto-electronic chip 500. At least, it is the brains with respect to the redundancy feature. The control portion 506 is physically made up of the hardware used to activate the individual devices based upon, for example, information stored in the storage, and/or to specify, update and/or change the stored information to initialize the chip or reprogram it following a failure. Depending upon the particular implementation, the control portion will be a processor, for example, a microprocessor operating under program control, a state machine, hard wired circuitry or some combination thereof.

Depending upon the particular implementation, the storage will be in the form of static random access memory (SRAM), dynamic random access memory (DRAM or RAM), or some form of read only memory (ROM) which may be, for example, a device such as a programmable

read only memory (PROM), an electronically programmable read only memory (EPROM), an electronically erasable programmable read only memory (EEPROM), a programmable logic device (PLD), etc. to name a few.

The storage 508 is accessible by the control portion 506 and is configured to allow the active device in each group to be specified. Optionally, the storage 508 can be further configured to keep track of redundant (i.e. back-up) devices and, as a further option, can be configured to specify the hierarchy or ordering for bringing on-line the remaining devices in the group if needed.

For example, Table 1 shows a simple table that can be employed for groups of device pairs. Each pair has a group address or identifier that uniquely identifies, directly or indirectly, each discrete group. A single bit is used to designate the active device, for example, with a binary 0 representing the first device in the group and a binary 1 representing the second device in the group.

Group Address	Active Device X_0

TABLE 1

Table 2 shows an alternative arrangement for identifying the active device in the storage. As with Table 1, an address or identifier uniquely identifies the particular group. Associated with that address is a two-bit binary number, where each bit corresponds to one device in the group and is used to signify whether that device is to be active.

Group Address	Active Device X_1X_0

TABLE 2

For example, a bit pattern of 00 would specify that neither device is active. Bit patterns of 01 or 10 would indicate that one or the other device in the pair is active. Depending upon the particular implementation, a bit pattern of 11 could, for example, be used to activate both devices for some special case or could simply be an invalid state.

Table 3 shows a similar arrangement for a chip having groups made up of four devices. In this case, a similar two bit binary number is used except, the actual number in binary is used to indicate the active device.

Group Address	Active Device
	X_1X_0

TABLE 3

For example, a 00 would indicate that the first device in the group is active, a 01 would indicate the second device in the group is active. A 10 would indicate that the third device is active and a 11 would indicate that the fourth device is active.

Table 4 shows a more complex arrangement for keeping track of the active devices in a particular array having individual four device groups. As shown Table 4 includes an address as noted above. In addition, an eight-bit binary number ($X_1X_0A_1A_0B_1B_0C_1C_0$) is used to identify

the particular laser device in the group that is the primary (i.e. active) device as well as a hierarchy for the remaining devices in the group.

Group Address	Primary Device	Secondary Device	Tertiary Device	Quartic Device
	X_1X_0	A_1A_0	B_1B_0	C_1C_0

TABLE 4

For example, for a particular address, an entry of 01110010 would indicate that the second device (01) is active. In the event that device was unusable or failed, the next device to be brought on-line is the fourth device. If that device were to fail, the next devices brought on-line thereafter would be, in order, the first followed by the third.

As can be appreciated, there are numerous ways other ways to identify active devices and/or specify alternative devices, either by employing some variant or combination of the above examples, or creating some other methodology, for example, by designating each laser with a unique address (irrespective of its group) and maintaining a list of the addresses for the lasers in each group in the order they are to be brought on line or providing space for settings for each laser, such as bias and modulation, and filling the setting information in for active lasers and/or setting the bias and/or modulation settings to zero and/or an invalid value to deactivate a laser.

In an alternative implementation, involving no storage for device selection, the devices incorporate fusible links that can be used to bring a device on- or off-line. For example, each device may incorporate two fusible links. Initially, neither link is blown so the device is inactive but available. To bring a device on line, circuitry is activated that causes a particular link to

blow and renders the device active. In the event that device dies some time in the future, other circuitry can be enabled to blow the remaining link, rendering the device inactive. A redundant device in the group can then be brought on-line by blowing the first link for that redundant device in a similar manner.

Still other alternative implementations use a combination of storage and hard wiring or fusible links to accomplish the functions of the control and/or storage.

FIG. 6 shows an opto-electronic device of the type shown in FIG. 5 in greater detail and constructed according to the principles of the invention. As shown, the detector portion 604 is made up of 36 individual detectors and the laser portion 602 is made up of 36 pairs of redundant lasers. As shown, the individual lasers 606, 608 in a group 610 are separated by device trenches 612 and the groups are separated from each other by grouping trenches 614.

In addition, there are available areas 616 between adjacent rows of the paired redundant lasers. Depending upon the particular implementation, those areas may be wholly unused, may be occupied by lasers of other wavelengths than those of the redundant pair, or may represent additional lasers of the same type as the redundant pairs which have been disabled for one reason or another.

FIG. 7 shows an opto-electronic chip 700 similar to that of FIG. 6 except that the array has been patterned as if four discrete devices were present to make up a group 702. However, each group contains only two lasers 704, 706.

FIG. 8 shows a chip 800 similar to the chip of FIG. 6 except that each individual group 802 is now made up of four individual lasers 804, 806, 808, 810.

FIG. 9 shows a chip 900 like the device of FIG. 5 but having pairs 902 of redundant photodetectors. As shown, the photodetectors are grouped, like the lasers of FIG. 6, by grouping trenches 904 and individual photo detectors 906, 908 within a group are separated by device trenches 910.

It is important to note in connection with redundant detectors, that the use of redundant detectors will require that either some additional device be used to redirect the incident light from one detector to the other detector in order to switch between them. Alternatively, the light can be defocused or defracted so as to be incident on all pertinent devices on both (in this case) as required. As should be apparent however, if redundant detectors are used and no light redirection is provided the system must be capable of accepting the losses due to such defocusing or defracting because the amount of incident light will be reduced exponentially as it is defocused to a larger and larger area to accommodate a larger number of redundant devices or a large pitch among them.

FIG. 10 shows a chip 1000 having an array 1002 similar to the array of FIG. 9 except that the array of FIG. 10 incorporates four redundant detectors 1004, 1006, 1008, 1010 per group.

Having shown a number of functional variants according to the invention, some examples of aspects usable for specific implementations will now be provided.

FIG. 11A shows one functional example of a circuitry arrangement for selecting from among two or more redundant devices according to the invention. In variants according to this example, a common data signal source 1102 is connected to all of the lasers 1104 in a group. As shown two or more lasers are in the group. A multiplexor 1106 (for 1 -to- 1 connections) or a

selector (for 1 -to- 1 or more connections) is inserted between the power source 1108 for the lasers and the lasers themselves. The control information (whether bit based or bias/modulation based) is used by the control portion 1110 to select which laser receives power. Alternatively, in some variants, the multiplexor can be replaced with a selector that can select any one or more of the lasers.

FIG. 11B shows another functional example of a circuitry arrangement from among two or more redundant devices according to the invention. In variants according to this example, a signal source 1112 is amplified by an amplifier 1114 and connected to the lasers 1106 via a multiplexor (for 1-to-1 connections) or a selector (for 1-to-1 or more connections). The multiplexor 1106 or selector is controlled in a similar manner to FIG. 11A.

FIG. 12 functionally shows a communication system including an opto-electronic transceiver 1200 incorporating the invention. As shown, the transceiver 1200 includes a chip 1202 incorporating redundant lasers 1204 in accordance with the invention. The transceiver 1200 is arranged so that each pair of lasers 1204 is coupled to a common fiber 1206. As shown, optical waveguides 1208 shaped like a "Y", are used to guide laser light from either laser 1210 in the pair to a common fiber 1206. In other variants, other forms of waveguides, or microlenses, gratings, fused fibers, etc., are used to couple the two or more lasers to a common fiber, the particular coupling method used being irrelevant to understanding the invention.

The transceiver 1200 also includes an electronic interface 1212 through which electrical signals, for example digital data can be received and sent. Depending upon the particular set up, the transceiver 1200 may be constructed to convert received digital signals into optical signals to

be transmitted over one or more fibers using the lasers, to a receiver 1214, which may be a standalone unit or be part of another transceiver, having photodetectors 1216. Additionally or alternatively, the transceiver 1200 may use those digital signals as control signals and/or receive the signals for use as in any conventional electro-optical transceiver. Similarly, the transceiver 1200 is constructed to detect incident light received on its detectors 1218 and convert that light to digital signals that are then output via the electronic interface in a conventional manner.

Advantageously, further variants can be constructed for automatic failover. FIG. 13 is a functional block diagram of one example way to integrate automatic failover. As shown, a group 1300 is made up of two lasers 1302, 1304 coupled to a common fiber, for example, a "cone" or "funnel" shaped waveguide 1305, that is common to both lasers 1302, 1304. The controller 1306 selects which laser is active by outputting a logical one or zero. A sensor 1308 monitors the output of the active laser, for example via sampling the output power of the laser when in use, and feeds the result back to a failover controller 1310, which may or may not be part of the controller 1306 but is functionally shown separately for purposes of understanding. The failover controller 1310 is used to determine if the active laser should be switched out in favor of another laser in the group based upon some value related to the performance of the laser – in this case output power. Depending upon the particular implementation, any of the many different known techniques for determining if a value is at a limit or within a range can be used. For example, a comparator may be used to directly or logically compare the sample to a threshold value, a trigger can be set to fire when the sample falls below a threshold, etc. . .

If, at some point, the laser power falls below the specified limit or goes outside the desired range, that laser will be deactivated in favor of another laser in the group using one of the techniques noted above. For example, as shown, the failover controller 1310 is connected to the storage 1312 so that if a failover for a laser is required, the failover controller 1310 changes the value in the storage 1312. That causes the controller 1306 to de-activate the one laser 1302 in favor of the backup laser 1304.

Depending upon the particular implementation, it may be desirable include circuitry or stored information such that, if a substitution of one device for another has occurred (whether automatically or manually) the "bad" device can be designated as such to prevent a switch back to the bad device if the backup device fails.

It should be understood that, although described largely in connection with an optical transceiver, the invention may be straightforwardly employed in an optical transmitter module or an optical receiver module, there being no need for any particular implementation to have two different types of devices (i.e. transmitters and receivers) to be present in the same unit to use the invention.

Moreover, it should be understood that the invention may be straightforwardly employed with any type of laser device, i.e. surface emitting lasers, distributed feedback (DFB) lasers, Distributed Bragg Reflector (DBR) lasers and/or any type of photodetectors.

Thus, while we have shown and described various examples employing the invention, it should be understood that the above description is only representative of illustrative embodiments. For the convenience of the reader, the above description has focused on a

representative sample of all possible embodiments, a sample that teaches the principles of the invention. The description has not attempted to exhaustively enumerate all possible variations. That alternate embodiments may not have been presented for a specific portion of the invention, or that further undescribed alternate embodiments or other combinations of described portions may be available, is not to be considered a disclaimer of those alternate embodiments. It can be appreciated that many of those undescribed embodiments are within the literal scope of the following claims, and others are equivalent.